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Associations between heat exposure, vigilance, and balance performance in summer tree fruit harvesters

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Abstract

Background—We sought to evaluate potential mediators of the relationship between heat exposure and traumatic injuries in outdoor agricultural workers.

Methods—Linear mixed models were used to estimate associations between maximum work-shift Wet Bulb Globe Temperature ($WBGT_{max}$) and post-shift vigilance (reaction time) and postural sway (total path length) in a cross-sectional sample of 46 Washington State tree fruit harvesters in August–September 2015.

Results—The mean (SD) $WBGT_{max}$ was 27.4 (3.2)°C in August and 21.2 (2.0)°C in September. The mean pre-work-shift participant urine specific gravity indicated minimal dehydration. Twenty-four percent of participants exhibited possible excessive sleepiness. There was no association between $WBGT_{max}$ and post-shift reaction time or total path length.

Conclusions—Heat exposure was not associated with impaired vigilance or balance in this study, in which the overall mean (SD) $WBGT_{max}$ was 25.9 (4.2)°C. However, the study identified opportunities to ensure adequate pre-work-shift hydration and to optimize sleep and work-shift timing in order to reduce occupational injury and heat-related illness risk.

Keywords

Heat exposure; Postural sway; Psychomotor vigilance

1. Introduction

Agriculture is among the industries with the highest rates of fatal injuries in the United States (US) (US Department of Labor, 2012). The burden of nonfatal injuries in agriculture

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is also substantial. Central and Eastern Washington State in the US are productive growing regions and large producers of tree fruit (WA Department of Agriculture, 2014). A study of Washington State Fund workers' compensation claims submitted for injuries that occurred in orchards reported that ladder-related claims, including claims for falls from ladders during tree fruit harvest activities, accounted for approximately half of claims involving more than medical treatment between 1996 and 2001 (Hofmann et al., 2006). These claims were also the most expensive, with a mean annual cost of $3.6 million, compared to claims accepted for other causes.

Several epidemiologic studies have reported an association between ambient heat exposure and injuries in agriculture. A study in Adelaide, Australia reported a 0.7% increase in daily agriculture, forestry, and fishing sector workers' compensation injury claims for each increase of 1°C daily maximum temperature for temperatures between 14.2°C and 37.7°C (incidence rate ratio 1.007, 95% confidence interval [CI] 1.001 to 1.013), using data from one weather station (Xiang et al., 2014). A study in Central/Eastern Washington State using workers' compensation outdoor agriculture traumatic injury claims, which included tree fruit injury claims, and modeled ambient exposure data reported traumatic injury odds ratios (95% Cl) of 1.14 (1.06, 1.22), 1.15 (1.06, 1.25), and 1.10 (1.01, 1.20) for daily maximum Humidex (apparent temperature) of 25–29, 30–33, and ≥34, respectively, compared to < 25, adjusted for self-reported duration of employment (Spector et al., 2016).

Human studies in laboratory settings have examined the relationship between heat exposure, dehydration, and health outcomes potentially associated with injury risk, including sustained concentration, or vigilance. In a study of young men exercising on a treadmill for 40 min at an ambient temperature of approximately 28°C and 42% relative humidity, exercise-related mild dehydration (mean percent body mass loss 1.6%) without hyperthermia was associated with adverse changes in vigilance (Ganio et al., 2011). In a similar study of women, mild dehydration was associated with reduced Profile of Mood States concentration scores (Armstrong et al., 2012). Decreased concentration could increase the risk of falls or other injuries.

Studies in laboratory settings have also evaluated balance performance in the setting of exercise, dehydration, and heat exposure. DiStefano et al. conducted a laboratory study of young men exercising on a treadmill for 90 min wearing a 20 kg rucksack in temperate (approximately 18°C and 50% relative humidity) and hot (approximately 34°C and 45% relative humidity) conditions at varying levels of hydration (Distefano et al., 2013). Balance was assessed by calculating the sway velocity and elliptical sway area from participants' centers of pressure. The authors found a significant increase in sway velocity and elliptical sway area following exercise in the hot condition with a mean body mass loss of 5.7%, compared to after exercise with smaller mean body mass losses of 1.4% and 3.8% in the temperate and hot conditions, respectively. Exercise is hypothesized to affect balance performance through its effects on fatigue, dehydration, inner ear changes, and hyperthermia (Distefano et al., 2013; Zemková and Hamar 2014). Balance impairment has been reported to be associated with falls in elderly individuals (Merlo et al., 2012; Muir et al., 2013; Maranesi et al., 2016).

The primary objective of this cross-sectional study, performed in Central/Eastern Washington State during pear and apple harvest in August and September, was to examine the relationship between ambient heat exposure and: 1) vigilance; and 2) balance performance in outdoor summer tree fruit harvesters. Vigilance was assessed using a mobile psychomotor vigilance task (PVT) to measure reaction time (Kay et al., 2013). Balance was assessed using a portable, low-cost balance board (Clark et al., 2010) to measure participant center of pressure deviations (postural sway) during quiet standing. We hypothesized that increases in maximum daily wet bulb globe temperatures are associated with increases in reaction time and postural sway in Washington outdoor summer tree fruit harvesters, as one potential mechanism of the increased risk of occupational injury observed in warm conditions in epidemiologic studies.

2. Materials and methods

2.1. Methods

2.1.1. Study sites and population—A convenience sample of adult (age 18 or older) tree fruit harvesters from six Central/Eastern Washington orchards (five pear orchards and one apple orchard) was recruited through University of Washington Pacific Northwest Agricultural Safety and Health (PNASH) Center contacts in 2015. The climate in Central/Eastern Washington is warm and dry, compared to the more mild and humid climate in Western Washington (Western Regional Climate Center, 2014). The Washington agricultural worker population includes seasonal and migrant workers, who are largely Spanish speaking (Washington State Employment Security Department, 2015). Potential participants were eligible to participate if they were paid by the amount harvested (piece-rate). Forty-six workers (34 during August pear harvest and 12 during September apple harvest) participated in the study for one work-shift each. Study procedures were reviewed and approved by the University of Washington Institutional Review Board, and participants provided informed consent prior to participation.

2.1.2. Individual and work factors—Demographic characteristics were assessed at the workplace on tablet computers using an audio computer-assisted self-interview survey instrument, which has been assessed for reliability and validity, as previously described (Spector et al., 2015). The survey was administered in Spanish or English, depending on the participant's primary language, and research staff members were available to answer questions in Spanish or English during the course of the survey. The survey was administered either the day before or the same day the worker participated in the field study. The survey asked whether a doctor or other health provider ever told a participant that they had: 1) conditions affecting balance, including stroke or problems with the inner ear and/or 2) sleep problems, including obstructive sleep apnea. Sleep was assessed using a Spanish language adaptation of the Epworth Sleepiness Scale (Hartford Hospital, 2006; Jimenez-Correa et al., 2009) and using a sleep quality question asking about how well participants slept in the past week, with response categories of very good, fairly good, fairly bad, very bad, and I don't know. The Epworth Sleepiness Scale (Johns, 1991) is a widely used scale that measures daytime sleepiness and is used to help diagnose sleep disorders. Epworth Sleepiness Scale scores are interpreted as: unlikely abnormally sleepy (score 0–7), average daytime sleepiness (score 8–9), may be excessively sleepy (score 10–15), and are excessively sleepy (score 16–24). Height and weight were measured the day the worker participated in the field study to calculate body mass index (BMI [kg/m^2]) (Centers for Disease Control and Prevention, 2014).

2.1.3. Heat stress and strain—Wet Bulb Globe Temperatures (WBGTs) were measured using a hand-held WBGT monitor (Extech HT30 WBGT Meter, Extech Instruments, Nashua, NH) near individual workers approximately every hour (median [range] duration between measurements: 63 [1,144] minutes). We focused on maximum measured work-shift WBGT ($WBGT_{max}$), as WBGT tended to increase to the end of the work-shift, when post-shift outcome measures were performed.

Work and break timing were observed by research staff and recorded on standardized data sheets. During work-shifts, which were on average 6.8, standard deviation 1.5, hours long, 83% (38/46) of participants took one break that was an average of about 20 min, generally in the mid-morning, to eat lunch. Otherwise, there were no breaks observed, and workers harvested steadily throughout their shifts except to stop to drink water or other beverages. Using American Conference of Governmental Industrial Hygienist (ACGIH) guidelines (ACGIH, 2015), all workers were determined to be performing moderate metabolic rate (300 Watt) work activities with 75–100% allocation of work in a work/recovery cycle.

We also calculated time-weighted average (TWA) WBGT values. To calculate the TWA WBGT, each WBGT measurement represented the WBGT for the time interval from the time of that reading to the previous reading. The WBGT measurements were weighted by the time interval, and all the weighted measurements in a given day were divided by the total shift duration for each worker to calculate the TWA WBGT for each participant.

To assess heat strain, workers' gastrointestinal temperatures and heart rates were continuously monitored using CorTemp™ wireless ingestible sensors (HQ Inc, Palmetto, FL) and Polar® chest band monitors (Polar Inc, Lake Success, NY), respectively. CorTemp™ sensors were ingested on average about 30 min before the start of the work-shift with lukewarm water. Heart rate and gastrointestinal temperature data were collected every 20 s. Core temperatures below 34°C or above 42°C and heart rates below 40 beats per minute (bpm) or above 200 bpm were considered outside of the physiologically expected range and excluded from the dataset. Five point rolling medians were calculated to smooth the data, and missing data were imputed as the median of the five values immediately before and five values immediately after the missing value. Consecutive missing values that exceeded 1 min were not imputed, and those points were excluded from the analysis.

2.1.4. Hydration—Pre- and post-work-shift hydration levels were assessed in the field by measuring urine specific gravity with a handheld refractometer (Atago A300CL, Tokyo, Japan). Plasma osmolality is most sensitive to small changes in hydration status but requires blood collection. Urine specific gravity is also sensitive to changes in acute hydration status (Oppliger et al., 2005) and is more practical to measure in field settings. Participants were provided with urine collection instructions and collection cups in brown paper bags before they started working and immediately after their work-shifts ended.

2.1.5. Psychomotor vigilance—Psychomotor vigilance task (PVT) testing is a validated method often used for assessing changes in psychomotor vigilance performance associated with sleep loss in clinical and research settings (Van Dongen and Dinges, 2005). The PVT has also been used to assess the effects of sleep restriction and exercise in warm conditions on reaction times (Tokizawa et al., 2015). The original versions of the PVT test require participants to press a physical button in response to a visual stimulus shown at random intervals on a computer screen. In this study, a 5 min mobile version of the PVT (PVT Touch application (Kay et al., 2013)) was used on an Android touchscreen tablet computer (Asus Eee Pad Transformer Prime 10.1 inch screen, ASUS Computer International, Fremont, CA, USA) to assess reaction times pre- and post-work-shift in the field. The Android device used has a timing resolution of approximately 2 ms; the PVT Touch application keeps graphics latency low (<2 ms) and optimizes garbage collection (automated memory management). Normal human reaction times are typically on the order of 250–500 ms.

Participants were asked to complete PVT testing before starting and after completing their work-shifts. The project team gave a demonstration of the PVT to participants in the morning prior to their work-shift. They were then asked to complete the PVT in chairs that were placed in the orchard rows, away from other workers, to minimize distractions. Efforts were made to have participants complete the PVT as soon as possible after their work-shifts. Response time and number of lapses (number of times at least 500 ms passed between the stimulus and the participant reaction) data were saved on tablets and downloaded at the end of each workday. Mean response time was calculated by averaging all responses that were not false starts (which have negative response times).

2.1.6. Balance performance—Force plates are used in clinical practice and research to estimate the center of pressure of a person standing. The center of pressure is the projection on the ground plane of the centroid of the vertical force distribution. Center of pressure has been used as an index of postural stability in standing (Ruhe et al., 2011). Center of pressure measurements can be collected over time, and the length of the path of the measurements has been used to assess postural sway, with a longer length indicating more sway and less stable balance. In this study, an inexpensive and portable video game control device (Wii Balance Board, Nintendo, Redmond, WA, USA) was used in the field to assess balance performance. The validity of the Wii Balance Board has been assessed against laboratory-grade force plates (Clark et al., 2010), with Pearson's correlation coefficients of center of pressure trajectories reported to be over 0.99 in the x and y directions (Huurnick et al., 2013).

Postural sway assessments were performed before and after work-shifts. The balance board was placed on a large piece of plywood, which was located on flat ground and confirmed using a bubble level. Foot templates were taped onto the Wii board so that all participants used the same foot placement. The templates were positioned so the heels were approximately 10 cm apart and toes angled approximately 30° away from the middle of the board. The project team made every effort to place the balance board in an area away from distraction but was constrained by orchard topography. Research staff demonstrated normal standing posture to participants in the morning before work-shifts started. Each participant stood on the balance board with their hands by their sides for 60 s with their eyes open and then 60 s with their eyes closed. Measurements were repeated with eyes closed to assess postural sway in the presence of vestibular input without visual input (Lion et al., 2010). Participants left their shoes on and focused on a visual “target” (a square of colored paper) located at eye-level approximately 2 m away when their eyes were open. Efforts were made to have participants complete their post-shift postural sway assessment as soon as they completed their work-shifts. Published studies suggest that postural control returns to baseline between eight and 13 min after exercise (Fox et al., 2008).

Center of pressure measurements were collected at 50 Hz during the postural sway assessments and transmitted via Bluetooth to a laptop computer. A LabVIEW program (National Instruments Corporation, Austin, TX, USA) was used to receive and record the data. A separate LabVIEW program was used to analyze center of pressure data to determine path length. The data analyzed were narrowed to a 30 s window for each of the four measurements (pre-shift and post-shift with eyes open and closed). To omit variability due to participants stepping on and off the board, the analysis was initiated approximately 200 μs after the participant stepped onto the board for a session. The total path length for the 30 s after the analysis began was calculated and used as the primary postural sway measurement. All measurements were analyzed independently by two research staff members, and results from each member were averaged and used as the final measurement for each participant. The measurements were compared and re-analyzed by a third project team member if the difference between the total path length as calculated by the first two members was greater than 10 cm.

2.1.7. Statistical analysis—Demographic, work, health, and environmental characteristics were examined using descriptive statistics. Urine specific gravity, PVT reaction time, number of lapses, and total path length were also examined using descriptive statistics, and pre- and post-shift values were compared using paired Student’s *t*-tests.

On the survey, no participants reported ever being told by a doctor or other health provider that they had health conditions affecting balance, including stroke or problems with the inner ear. All 46 participants were included in inferential analyses of the relationship between $WBGT_{max}$ and postural sway. Two participants were excluded from inferential analyses of the relationship $WBGT_{max}$ and reaction time because one participant was missing a pre-shift PVT test value and one participant was missing a post-shift PVT test value.

The associations of $WBGT_{max}$ with post-shift PVT reaction time and, secondarily, number of lapses, were assessed using linear mixed effects models with intercept random effects for worksites, using the Kenward-Rogers method for small samples (Kenward and Roger, 1997; Halekoh and Højsgaard, 2014). PVT reaction times were log transformed because distributions were wide and right skewed. PVT models were adjusted for pre-shift PVT reaction time (Model 1) and the following potential confounders. Model 2 adjusted for pre-shift PVT reaction time and additionally adjusted for sleep quality in the past week (fairly bad [reference category], fairly good, very good). Model 3 adjusted for variables in Model 2 and duration of work-shift. Model 4 adjusted for all variables in Model 3 and age, gender (male [reference category], female), and BMI.

The association of $WBGT_{max}$ with total path length was modeled using a similar approach as for reaction time. Total path length models were adjusted for pre-shift path length (Model 1) and the following potential confounders. Model 2 adjusted for pre-shift path length and additionally adjusted for the duration of work-shift. Model 3 adjusted for all variables in Model 2 and age, gender (male [reference category], female), and BMI. Analyses were conducted using R 3.3.1 (R Foundation, Vienna, Austria) (R Development Core Team, 2011).

3. Results

3.1. Participant, work, and environmental characteristics

Participant, work, and environmental characteristics are shown in Table 1. The mean (standard deviation) age of participants was 39.1 (14.1) years, and the majority (85%) of participants were male. Ninety-eight percent of participants described themselves as Latino/Latina, and 96% reported Mexico or Central America as their birthplace. Compared to pear harvest workers (n = 34), apple harvest workers (n = 12) had an older mean age (47.2 versus 36.3 years) and a lower percentage of males (58% versus 94%). The mean (standard deviation) BMI among participants was 27.9 (4.2) kg/m^2, which corresponds to overweight (Centers for Disease Control and Prevention, 2014). Six (13%) participants reported fairly bad sleep quality in the past week, and 11 (24%) participants' sleepiness scale scores fell in the "may be excessively sleepy" (score: 10–15) range. One pear harvester's sleepiness scale score was above 15, but that participant did not report being told by a healthcare provider that they had a sleep problem.

Sixty-five percent of all participants reported ten or more years of work experience, and a larger percent of apple harvest workers reported ten or more years of work experience (92%) than pear harvest workers (56%) (Table 1). The mean (standard deviation) length of the work-shift was 6.8 (1.5) hours, with workers starting on average around 6 a.m. and finishing around 1 p.m. The mean (standard deviation) $WBGT_{max}$ during participants' work-shifts was 27.9 (3.6)°C in August and 21.2 (2.0)°C in September. The $WBGT_{max}$ range was 22.0–33.1°C in August and 19.0–22.9°C in September. Twenty-five (74%) of workers exceeded the ACGIH Heat Stress Action Limit (AL) (WBGT 25°C) and 15 (44%) exceeded the Threshold Limit Value (TLV) (WBGT 28°C) in August. No workers exceeded the ACGIH AL or TLV in September. The mean (standard deviation) time-weighted average WBGT was 22.3 (2.5)°C in August and 15.9 (1.0)°C in September.

3.2. Hydration status, gastrointestinal temperature, heart rate, psychomotor vigilance, and postural sway

Measures of hydration status, gastrointestinal temperature, heart rate, psychomotor vigilance, and postural sway are shown in Table 2. Mean (SD) pre-shift urine specific gravity was 1.025 (0.007), which is considered minimal dehydration (1%–3% of body weight) (Oppliger et al., 2005). There was no significant change in urine specific gravity comparing pre- and post-shift urine specific gravity values ($t[44] = 0.91$, $p = 0.400$). Fifty-four percent (n = 13) of those exceeding the ACGIH AL exceeded the maximum recommended heart rate (sustained heart rate for several minutes above 180 beats per minute minus the age of the worker) or core temperature (38.5°C) for acclimatized workers, per ACGIH guidelines (ACGIH, 2015), indicating heat strain.

Mean (standard deviation) pre-shift PVT reaction times were 644 (288) ms for pear harvesters and 911 (508) ms for apple harvesters. For all participants, the pre-shift mean (standard deviation) reaction time was 715 (373) ms, and the post-shift mean (standard deviation) reaction time was 611 (338) ms. There was a significant decrease in PVT mean reaction time and number of lapses across the shift for all participants (t[43] = 3.4, p= 0.002 and t[43] = 2.3, p= 0.029, respectively). Mean (standard deviation) total path length with eyes open was 45.6 (12.9) cm pre-shift and 37.7 (10.2) cm post-shift. There was a significant decrease in mean path length across the shift for all participants for both eyes open (t[45] = 3.8, p < 0.001) and eyes closed (t[45] = 3.1, p= 0.004) conditions.

3.3. Association between heat exposure, reaction time, and total path length

Results of linear mixed effects models are shown in Table 3 and Table 4. There was no significant association between $WBGT_{max}$ and post-shift PVT reaction time after adjustment for pre-shift reaction time, sleep quality, shift duration, age, gender, and BMI (Table 3). Similar findings were observed for the secondary PVT number of lapses outcome. There were no significant associations between $WBGT_{max}$ and total path length with eyes opened or closed after adjustment for pre-shift total path length, shift duration, age, gender, and BMI (Table 4).

4. Discussion

In this study of outdoor agricultural workers, who are at risk for heat-related illness and traumatic injuries (Hofmann et al., 2006; US Department of Labor, 2012; WA Department of Agriculture, 2014; Xiang et al., 2014; Spector et al., 2016), heat exposure was not associated with impaired vigilance or balance performance after steady harvest work with minimal breaks in heat exposure conditions characterized by an overall mean (SD) maximum measured work-shift WBGT of 25.9 (4.2)°C. Impaired vigilance and balance performance are two of a number of potential mediators of the relationship between heat exposure and fall-related injuries (Merlo et al., 2012; Muir et al., 2013; Maranesi et al., 2016). The current study focused on Washington pear and apple harvesters in August and September. In a recent epidemiological study of outdoor agricultural workers in Washington, an increased risk of traumatic injuries was seen with increasing heat exposure to a maximum daily Humidex of approximately 33 (Spector et al., 2016). Cherry harvest duties that occurred during June and July were associated with a particularly high risk of traumatic injuries in warm conditions (odds ratio [95% confidence interval] of traumatic injury 1.57 [1.20, 2.34] for Humidex 30–33, compared to less than 25). Associations between heat exposure and apple harvest injuries occurring during the cooler August to October time period were less pronounced than for cherry harvest occurring during June and July.

Results of mixed models indicated no association between heat exposure and post-shift PVT reaction time or number of lapses after adjustment for relevant confounders. Laboratory studies have reported associations between mild dehydration (mean body mass loss 1.6%) without hyperthermia, in the setting of exercise at ambient temperatures of approximately

28°C and 42% relative humidity, and adverse changes in vigilance in young men (Ganio et al., 2011). Cognitive performance was reported to be adversely affected in foundry workers exposed to WBGTs of 31–35°C compared to unexposed workers (WBGT 17°C) (Mazlomi et al., 2016). We used maximum measured work-shift Wet Bulb Globe Temperature ($WBGT_{max}$) as the form of the exposure in our models. $WBGT_{max}$ was unlikely to be the true work-shift maximum, as WBGT was not continuously measured, and did not reflect the variability in exposure throughout the work-shift. TWA WBGTs were substantially lower, and it is possible that conditions were not warm enough during our study, particularly during apple harvest in September, to observe an effect of heat exposure on vigilance.

Mean PVT reaction time was higher pre-shift compared to post-shift. Psychomotor vigilance performance as measured with the PVT does not exhibit a substantial practice effect (Van Dongen and Dinges, 2005). However, temporal variability in vigilance has been clearly documented to be associated with the interaction between homeostatic and circadian processes of sleep/wake regulation (Van Dongen and Dinges, 2005). In the morning hours, there is little homeostatic pressure for sleep and little circadian pressure for wakefulness, while later in the day, the homeostatic pressure for sleep dissipates and the circadian pressure for wakefulness rises. This phenomenon could explain why mean PVT reaction times were improved (lower) later in the day.

On average, work shifts ended slightly later in September than in August, and sampled harvest days in August were on average warmer than sampled days in September. If PVT reaction times were expected to be slightly higher later in the afternoon, then time of day could have confounded the association between heat exposure and PVT reaction times and contributed to the observed results, which are counter to our hypothesis. However, we adjusted for shift duration, which is likely related to time awake and fatigue, in fully adjusted models of our outcomes, and shift duration was closely related to time of day post-shift that outcomes were measured. In a post hoc analysis, adjusting for categories of times post-shift PVT measurements were made instead of shift duration did not substantially affect our results of the relationship between heat exposure and PVT reaction times.

Sleep was not optimal in a relatively large proportion of workers in the study. Twenty-four percent of participants exhibited sleepiness scale scores that fell in a range suggesting that they “may be excessively sleepy” [score: 10–15]. Chronic sleep restriction is associated with cognitive performance deficits, which can increase injury risk (Van Dongen et al., 2003). Sleep restriction has been reported to be associated with an increased risk of heat-related illness (Tokizawa et al., 2015). Work-shifts are often recommended to start earlier in the morning to avoid work during the hotter parts of the day (Jackson and Rosenberg, 2010), but early morning shifts may be associated with shorter sleep times (Ingre et al., 2008). In this study, longer duration of the work-shift was positively correlated with higher post-shift PVT reaction times. Further studies are needed to inform recommendations for optimizing both sleep and work-shift timing in order to reduce the risk of both occupational injuries and heat-related illness in outdoor agricultural workers.

In this study, longer work-shift duration was positively correlated with higher post-shift total path length. Exercise, particularly prolonged exercise, has been proposed to be related to increased postural sway (Zemková and Hamar 2014). Results of mixed models revealed no association between heat exposure and post-shift total path length, after adjustment for relevant confounders. If it is assumed that the mechanism of this association is mediated by dehydration (Distefano et al., 2013), workers were likely not dehydrated enough by the end of the shift to exhibit changes in postural sway. Previously published laboratory studies have demonstrated increases in postural sway at substantially higher levels of dehydration (more than 5% mean body mass loss) than demonstrated in workers in this study. Inferences from results of eyes closed trials were similar to eyes open trials, suggesting intact vestibular input to balance performance, in the absence of visual input, during measurements (Lion et al., 2010).

Workers in this study exhibited a mean pre-shift urine specific gravity consistent with dehydration at a minimal level (1–3% of body weight) (Oppliger et al., 2005). Workers started work-shifts on average around 6 a.m. and provided urine before they started working. Measures of hydration status from the first morning urine of the day have been recommended to assess hydration status in athletes (Shirreffs and Maughan, 1998). Information was not available about whether the pre-shift urine samples that participants in this study provided were the first void of the day or whether workers ingested food or beverage prior to providing urine samples. There was no significant increase in mean urine specific gravity across the work-shift, although changes in urine specific gravity may lag behind plasma osmolality during progressive acute dehydration (Popowski et al., 2001). Adequate hydration is critical for thermoregulation and the prevention of heat-related illness (Sawka et al., 2011). Our findings suggest that additional efforts to ensure that workers are adequately hydrated at the start of the work-shift may be indicated to help prevent heat-related illness.

4.1. Limitations

This study has several important limitations. First, the busy orchard environment in which the PVT and postural sway assessments were performed was difficult to control. Mornings tended to be darker and quieter, so any effect of worker distraction on increased PVT reaction time or postural sway from nearby work or activity would have been expected to be more pronounced post-shift. Yet, both mean PVT reaction time and total path length were higher pre-shift compared to post-shift. Second, although an effort was made to perform PVT and total path length measurements immediately after the work-shift ended, we did not systematically account for the time period between the end of work-shift and post-shift measurements. Although workers did not always end their shifts at the same time, there was only one balance board available to perform total path length measurements when workers did end at the similar times. If measurements were made too long after work ended, recovery of function could have occurred, and this may have resulted in a bias of the association between heat exposure and reaction time and postural sway toward the null. Third, heat stress includes net exposures from a combination of environmental factors, clothing, and metabolic heat (ACGIH, 2015). The exposure in this study ($WBGT_{max}$) did not take into account clothing or individual-level metabolic heat estimates. As a group, workers were determined based on researcher field observations to be performing moderate metabolic rate (300 Watt) work activities. Preliminary results of an additional analysis of triaxial accelerometer (ActiGraphs wGT3X-BT, ActiGraph; Pensacola, FL) data measured in study participants confirms primarily moderate energy expenditure activity during harvest. There was not substantial variability in clothing worn, based on field observation data. In general, participants started their work-shifts wearing two or three layers of clothing, including short or long-sleeved shirts underneath hooded sweatshirts or button-down shirts, on their torsos. Most participants kept all layers on for the duration of their shifts. All participants wore long pants, typically jeans or cargo pants.

A fourth limitation is that, given the small size of the study, it was difficult to perform and interpret stratified analyses or adjust for all possible potential confounders. Fifth, CorTemp™ sensors were ingested on average about 30 min before the start of the work-shift and did not equilibrate until approximately 90 min after ingestion. It was unfortunately logistically not possible to arrange for participants to take sensors the previous night or earlier in the morning before the work-shift. However, core temperature exceedances indicating heat strain, as defined using ACGIH guidelines, generally occurred during hotter, later times in work-shifts. A delay in initial equilibration of CorTemp™ sensors during the early, cooler part of the work-shift would have been unlikely to affect our results. Sixth, harvest workers were not randomly sampled, and participating workplaces may have been more likely to limit worker heat stress. It is also possible that participating workers were systematically different, for example better acclimatized, compared to other Washington outdoor tree fruit harvesters and therefore less likely to exhibit impaired vigilance and postural sway in the heat. Finally, the results of this study may not be generalizable to outdoor agricultural working populations outside of Washington.

5. Conclusions

Heat exposure was not associated with impaired vigilance or postural sway in this cross-sectional study of Washington pear and apple harvesters. Future, larger, repeated-measures studies should explore this association in highly heat-exposed workers with high injury rates, including cherry harvest workers and construction workers. Studies should also consider other mechanisms that may explain the finding of increased injuries in the heat observed in epidemiological studies. This study identified opportunities for employers to support enhanced worker hydration at the start of work-shifts and to optimize work-shift timing, with consideration of optimizing sleep and reducing heat exposure, in order to reduce the risk of occupational injuries and heat-related illness and enhance work productivity.

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Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienist

AL	Action Limit
BMI	Body Mass Index
CI	Confidence Interval
PNASH	Pacific Northwest Agricultural Safety and Health Center
PVT	Psychomotor Vigilance Task
SD	Standard Deviation
TLV	Threshold Limit Value
TWA	Time-Weighted Average
US	United States
WBGT	Wet Bulb Globe Temperature

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Table 1

Participant, work, and environmental characteristics, n (%) or mean (SD).

Characteristic	August pear harvest (n = 34)	September apple harvest (n = 12)	All (N = 46)
Age (years)	36.3 (13.5)	47.2 (13.0)	39.1 (14.1)
Male gender	32 (94%)	7 (58%)	39 (85%)
Latino/a (n = 45)	32 (97%)	12 (100%)	44 (98%)
Born in Mexico/Central America	32 (94%)	12 (100%)	44 (96%)
Years of work experience			
<1 year	5 (14%)	0	5 (11%)
1–2 years	3 (9%)	0	3 (6%)
3–5 years	4 (12%)	0	4 (9%)
6–9 years	3 (9%)	1 (8%)	4 (9%)
10 or more years	19 (56%)	11 (92%)	30 (65%)
Length of work-shift (hours)	7.0 (1.3)	6.4 (1.9)	6.8 (1.5)
Shift start time	5:50 a.m. (27 min)	6:36 a.m. (10 min)	6:02am (31 min)
Shift end time	12:49 p.m. (76 min)	1:02 p.m. (106 min)	12:52pm (85 min)
Body mass index (kg/m^2)	27.6 (3.9)	28.7 (5.1)	27.9 (4.2)
Sleep quality in the past week			
Very good	16 (47%)	7 (58%)	23 (50%)
Fairly good	14(41%)	3 (25%)	17 (37%)
Fairly bad	4 (12%)	2 (17%)	6 (13%)
Very bad	0	0	0
I don’t know	0	0	0
Sleepiness scale score	6.6 (3.9)	5.5 (4.9)	6.3 (4.2)
Unlikely abnormally sleepy (score: 0–7)	23 (67%)	9 (75%)	32 (70%)
Average daytime sleepiness (score: 8–9)	2 (6%)	0	2 (4%)
May be excessively sleepy (score: 10–15)	8 (24%)	3 (25%)	11 (24%)
Are excessively sleepy (score: 16–24)	1 (3%)	0	1 (2%)
Maximum measured work-shift Wet Bulb Globe Temperature	27.9 (3.6)°C	21.2 (2.0)°C	25.9 (4.2)°C
Time-weighted average Wet Bulb Globe Temperature	22.3 (2.5)°C	15.9 (1.0)°C	20.7 (3.6)°C

Table 2

Measures of hydration, psychomotor vigilance, and balance performance, mean (SD).

Characteristic	August pear harvest (n = 34)		September apple harvest (n = 12)		All (N = 46)		
	Pre-shift	Post-shift	Pre-shift	Post-shift	Pre-shift	Post-shift	*t*-test, *p* value
Urine specific gravity[a]	1.025 (0.008)	1.024 (0.007)	1.028 (0.004)	1.025 (0.004)	1.025 (0.007)	1.025 (0.007)	$t(44) = 0.91$, $p = 0.400$
Psychomotor vigilance task (PVT) reaction time (ms)[a]	644 (288)	553 (285)	911 (508)	772 (428)	715 (373)	611 (338)	$t(43) = 3.4$, $p = 0.002$
Psychomotor vigilance task (PVT) number of lapses Balance performance, total path length (cm)	21 (15)	15 (14)	27 (13)	28 (15)	23 (15)	18 (15)	$t(43) = 2.3$, $p = 0.029$
Eyes open	45.7 (13.8)	37.1 (10.6)	45.3 (10.4)	39.4 (9.1)	45.6 (12.9)	37.7 (10.2)	$t(45) = 3.8$, $p < 0.001$
Eyes closed	63.8 (19.3)	55.8 (16.4)	62.0 (20.6)	53.1 (12.4)	63.3 (19.4)	55.1 (15.4)	$t(45) = 3.1$, $p = 0.004$

[a] One pear harvest worker pre-work-shift and one pear harvest worker post-work-shift values missing.

Table 3

Effect estimates (95% confidence intervals) from linear mixed effects models of post-shift mean reaction time (milliseconds), N = 44.

Mean reaction time	Model 1[a]	Model 2[b]	Model 3[c]	Model 4[d]
Intercept	2.75 (1.40, 4.09)	2.89 (1.44, 4.35)	2.74 (1.32, 4.16)	2.82 (1.07, 4.58)
$WBGT_{max}$	−0.03 (−0.05, 0.01)	−0.03 (−0.06, 0.01)	−0.04 (−0.07, 0.00)	−0.03 (−0.07, 0.01)
Pre-shift mean reaction time (ms)	0.65 (0.47, 0.82)	0.63 (0.44, 0.82)	0.61 (0.45, 0.79)	0.62 (0.41, 0.82)
Sleep quality (ref: fairly bad)				
Fairly good	–	0.10 (−0.18, 0.39)	0.13 (−0.15, 0.40)	0.13 (−0.17, 0.42)
Very good	–	0.07 (−0.19, 0.33)	0.07 (−0.18, 0.32)	0.10 (−0.17, 0.36)
Shift duration (hrs)	–	–	0.06 (−0.01, 0.12)	0.06 (−0.02, 0.15)
Age	–	–	–	0.00 (−0.01,0.01)
Gender (ref: male)				
Female	–	–	–	0.12 (−0.19, 0.42)
Body mass index (kg/m^2)	–	–	–	−0.01 (−0.03, 0.02)

[a] Adjusted for pre-shift reaction time.

[b] Adjusted for pre-shift reaction time and sleep quality.

[c] Adjusted for pre-shift reaction time, sleep quality, and shift duration.

[d] Adjusted for pre-shift reaction time, sleep quality, shift duration, age, gender, and body mass index.

Table 4

Effect estimates (95% confidence intervals) from linear mixed effects models of total path length, N = 46.

Eyes open	**Model 1[a]**	**Model 2[b]**	**Model 3[c]**
Intercept	25.34 (−10.07, 60.74)	24.60 (−7.31, 56.50)	33.77 (−3.86, 71.40)
$WBGT_{max}$	−0.01 (−1.35, 1.34)	−0.56 (−1.85, 0.73)	−0.90 (−2.40, 0.59)
Pre-shift total path length (ms)	0.26 (0.04, 0.49)	0.29 (0.06, 0.51)	0.29 (0.05, 0.54)
Shift duration (hrs)	–	2.08 (−0.29, 4.46)	2.43 (−0.60 5.47)
Age	–	–	−0.08 (−0.34, 0.18)
Gender (ref: male)			
Female	–	–	−3.27 (−14.52, 7.97)
Body mass index (kg/m^2)	–	–	0.03 (−0.77, 0.83)
Eyes closed	Model 1[a]	Model 2[b]	Model 3[c]
Intercept	17.62 (−22.73, 57.98)	6.60 (−34.16, 47.37)	−9.27 (−66.73, 48.18)
$WBGT_{max}$	0.54 (−1.00, 2.09)	0.25 (−1.39, 1.90)	0.41 (−1.89, 2.71)
Pre-shift total path length (ms)	0.37 (0.15, 0.59)	0.36 (0.15, 0.57)	0.36 (0.13, 0.60)
Shift duration (hrs)	–	2.81 (−0.57, 6.19)	2.33 (–2.18, 6.84)
Age	–	–	0.05 (−0.33, 0.42)
Gender (ref: male)			
Female	–	–	2.96 (−14.37, 20.30)
Body mass index (kg/m^2)	–	–	0.45 (−0.68, 1.59)

[a] Adjusted for pre-shift total path length.

[b] Adjusted for pre-shift total path length and shift duration.

[c] Adjusted for pre-shift total path length, shift duration, age, gender, and body mass index.